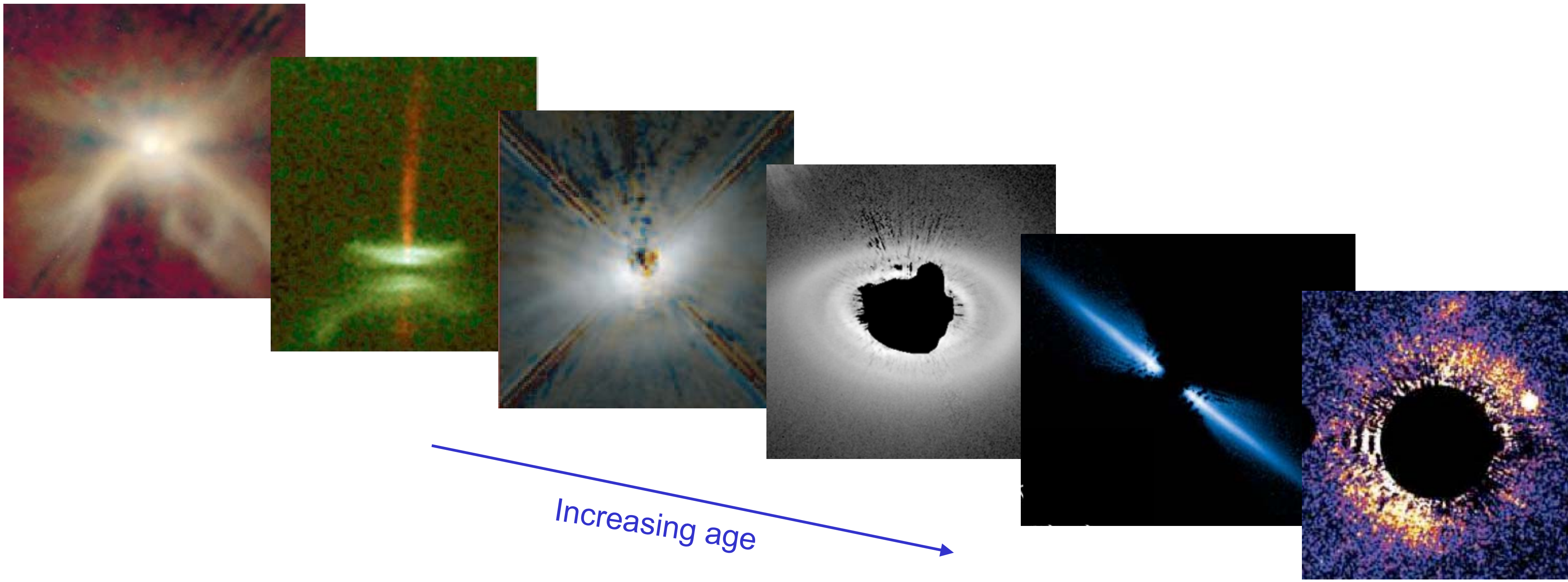
Scattered Light Imaging of Disks

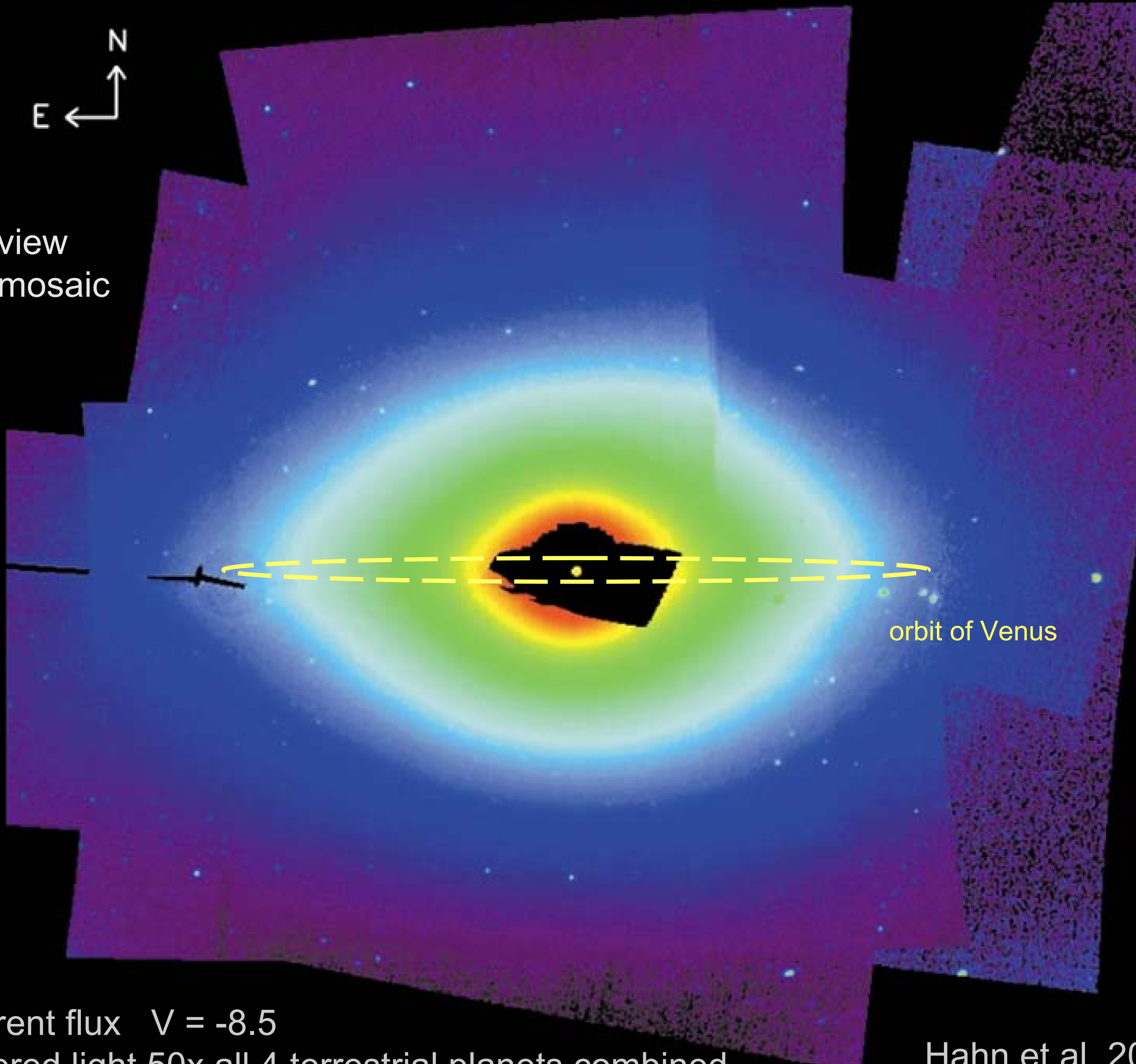


Marshall Perrin

UCLA

Clementine Spacecraft observations of the Zodiacal Light
Hahn et al. 2002

60º Field of view
Clementine mosaic

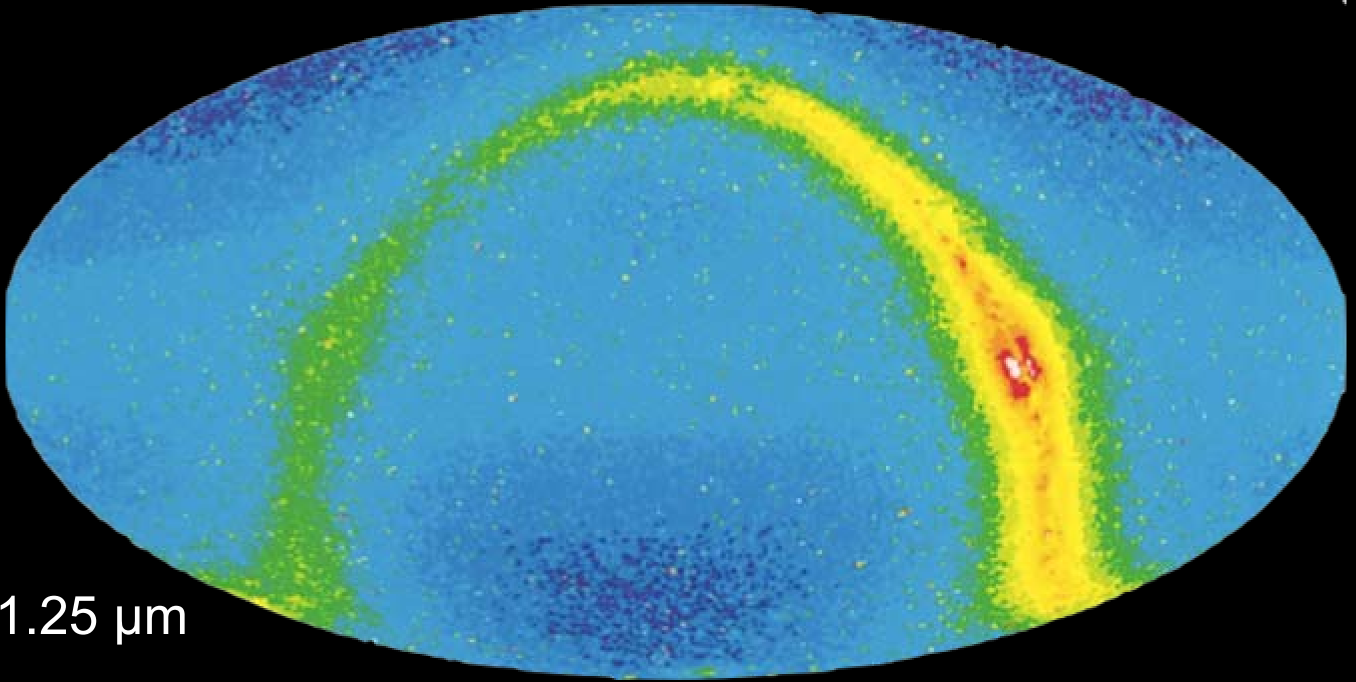


Total apparent flux   V = -8.5
Total scattered light 50x all 4 terrestrial planets combined

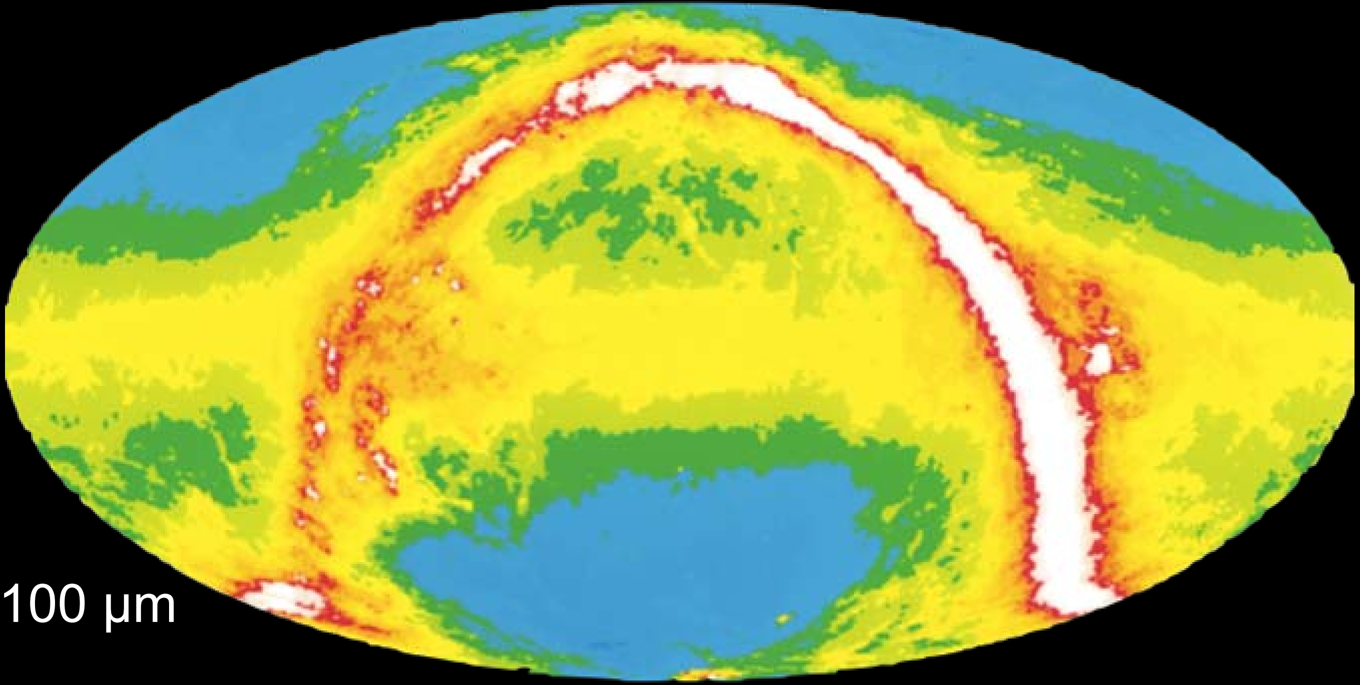
Hahn et al. 2002

COBE DIRBE all-sky maps

Kelsall et al. 1998

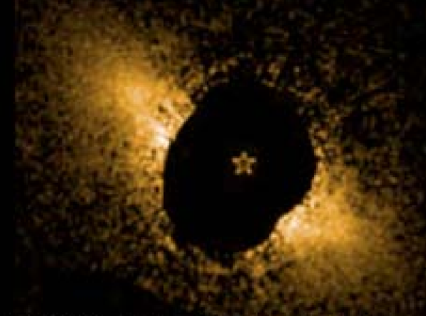


Kuiper Belt
L_{disk}/L_{*} ~1e-6?

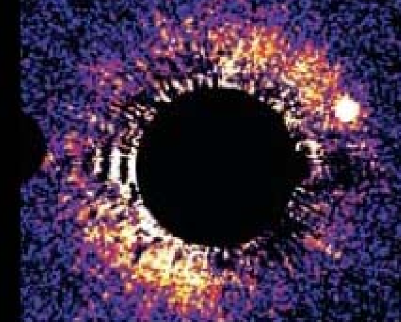


HR 4796 Krist et al. 2007

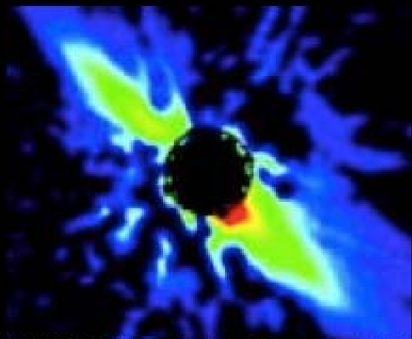
HD 15115 Kalas et al. 2007



HD 10647 Stapelfeldt et al. in prep

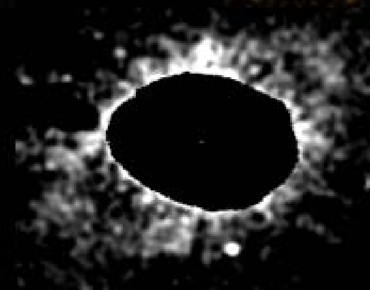


HD 53143 Kalas et al. 2006

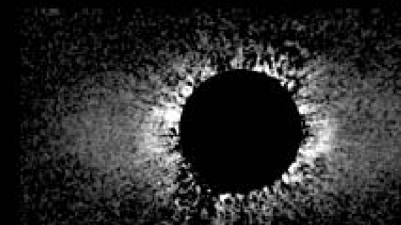


HD 32297 Schneider et al. 2006

HD 181327 Schneider et al. 2006



HD 207129 Krist et al. in prep

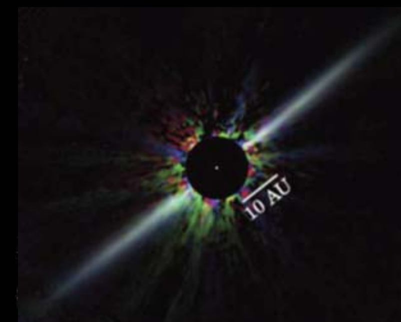


HD 92945
Golimowski et al. 2006

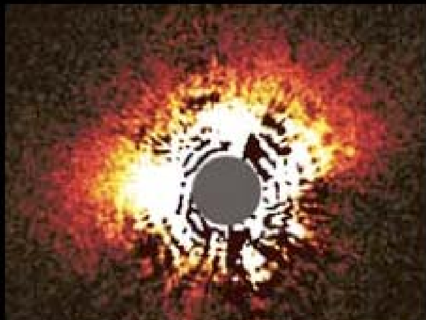
Fomalhaut Kalas et al. 2005

HD 139664 Kalas et al. 2006

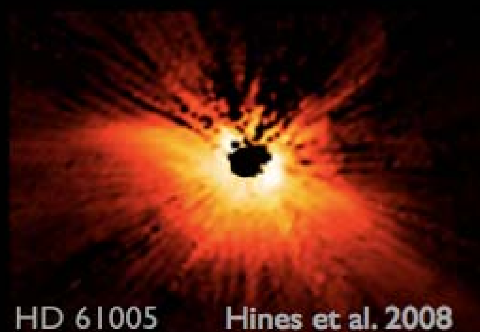
HD 107146 Ardila et al. 2004



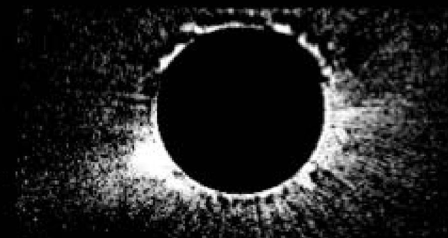
AU Mic
Fitzgerald et al. 2006



HD 15745 Kalas et al. 2007



HD 61005 Hines et al. 2008



HD 202917 Krist et al. in prep

Beta Pic
Golimowski et al. 2006

Scattered Light Imaging Goals

Constrain the overall architecture of planetary systems.

High angular resolution imaging breaks degeneracies from SEDs and spectra.

Investigate disk evolution over time

Planet formation! Do not neglect primordial disks.
later: delivery of volatiles, heavy bombardments, etc.

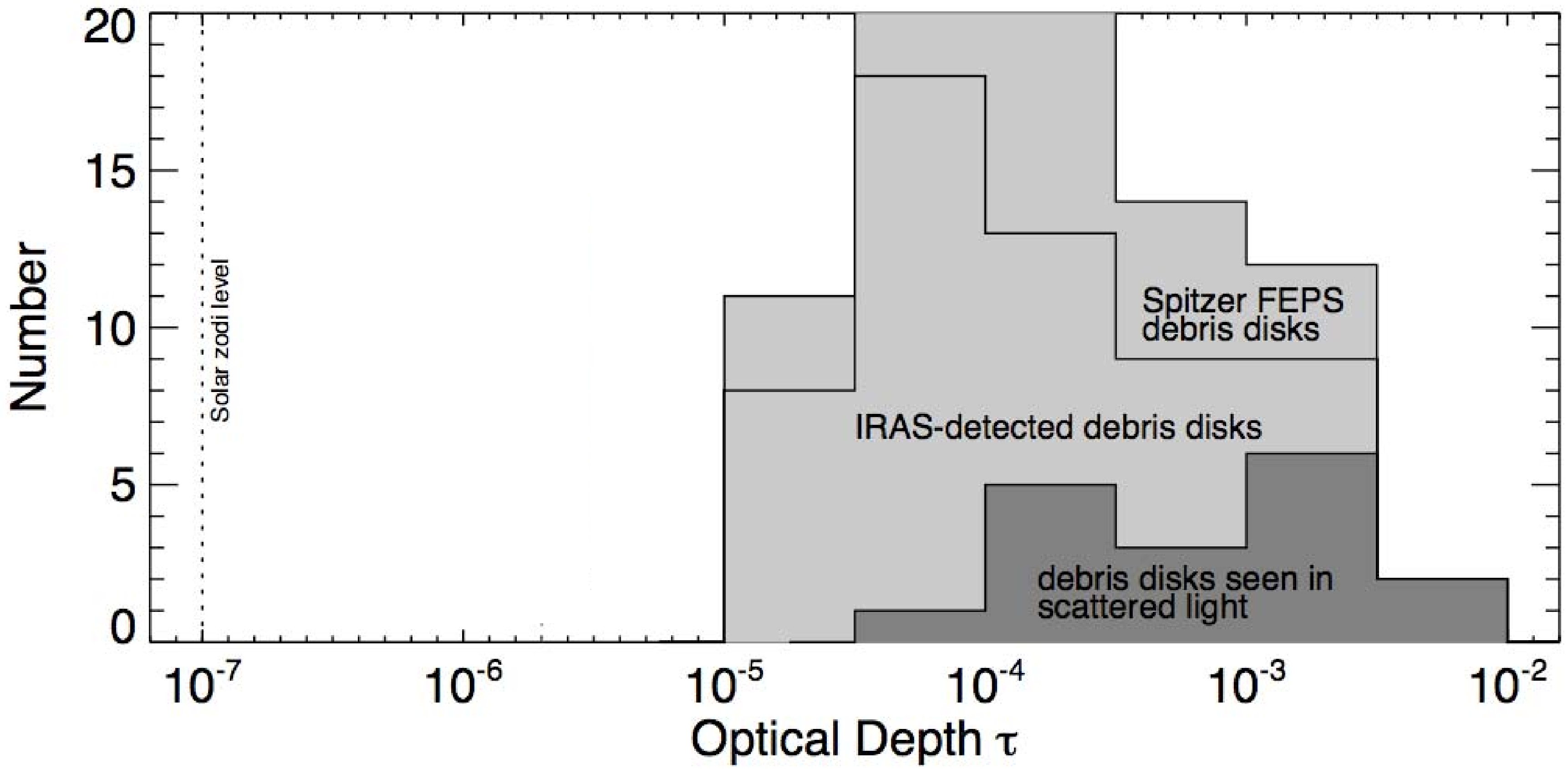
Characterize disk/planet interactions

Observe warps, gaps, asymmetries that hint at larger bodies

Measure properties of scattering particles

multiwavelength imaging and polarimetry are necessary

Just the tip of the iceberg…



IRAS data from Zuckerman & Song (2004.
Debris disk values from P. Kalas, J Krist, & circumstellardisks.org
FEPS data from Hillenbrand et al. (2008)

Future prospects - ground

Extreme AO systems will reach contrasts 10-30x better than currently available with HST.

$L_{disk}/L_{*} \geq 1e\text{-}5$

Near term: Gemini GPI, VLT SPHERE.

IWA ~ 0.2”, dark hole outer radius ~ 1.4”

GPI: NIR imaging polarimetry at 1.0-2.5 µm

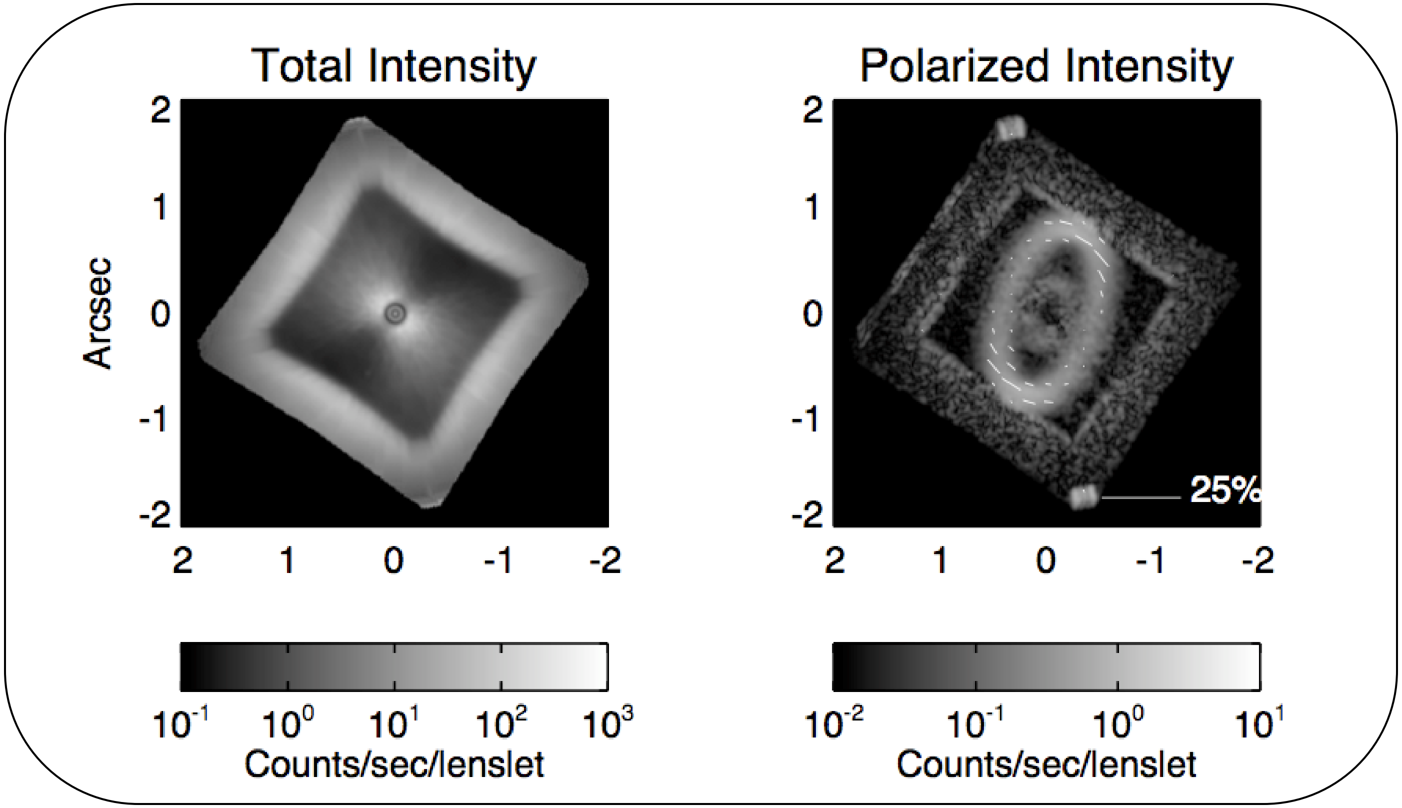
SPHERE: NIR & Visible Imaging polarimetry

Long term: ELTs?

TMT PFI design study predicts not much greater contrast than GPI, but IWA=0.03”

Goal is observing planets forming in disks in Taurus

Future prospects - ground



Simulated 1 hr GPI image - I=5 star at 20 pc

H band imaging polarimetry 100x speckle suppression

Outer & inner disks have L_{disk}/L_{*} = 1e-4 and 1e-5, respectively

Future prospects - space

Scattered light imaging at levels of < 100 zodi will likely require observations from space

SMEX scale: (e.g. EXCEDE, Schneider et al.)

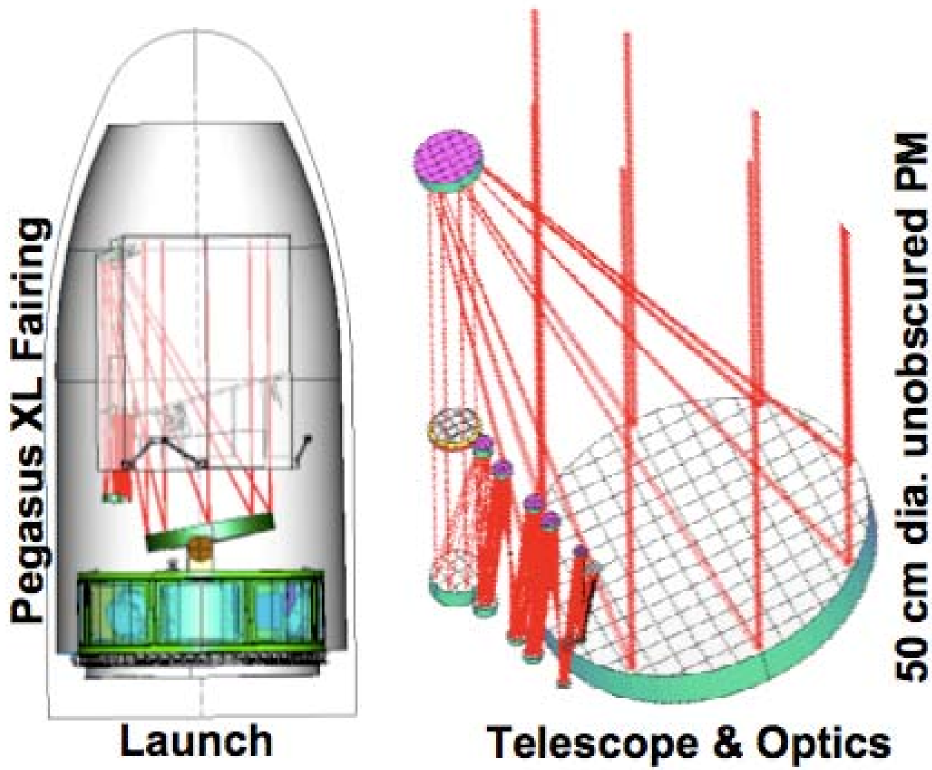
~0.5 m, PIAA coron., dual-channel polarim. 10-100 zodis

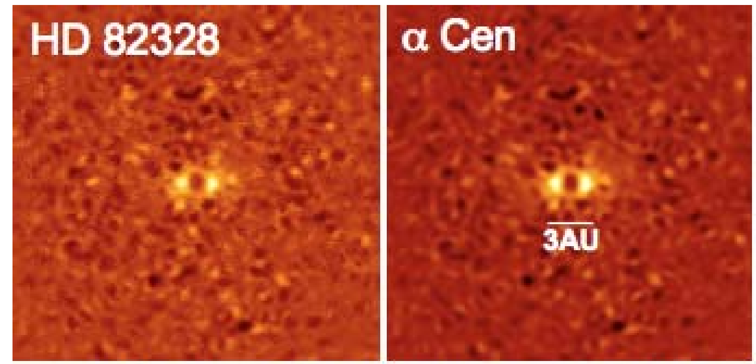
Discovery scale: (e.g. ECLIPSE, Trauger et al.)

~2 m., active optics, PIAA or SP coron.

1000x better contrast than HST
sensitive to <= 10 zodis

Potential for *small* missions

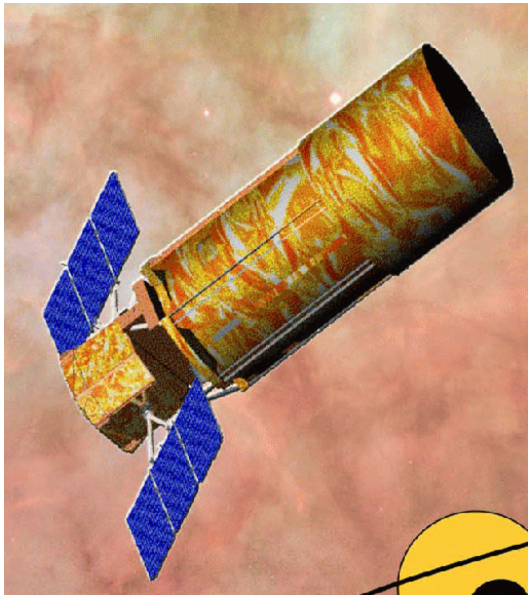




Simulated PSF-subtracted EXCEDE images of hypothetical 100 "zodi" SB(r) ~ $r^{-2.4}$ zodiacal debris systems about nearby sun-like stars. With polarimetric "speckle nulling", EXCEDE's reach will further extend to 10-20 zodi debris systems with strongly polarizing dust.

Figures from G. Schneider and the EXCEDE team

Medium-scale (~2m) missions



Left: Proposed ECLIPSE 2 m coronagraph

Right: Simulated ECLIPSE image of Altair with 1 zodi in the 2-3.5 AU region (Trauger et al.)

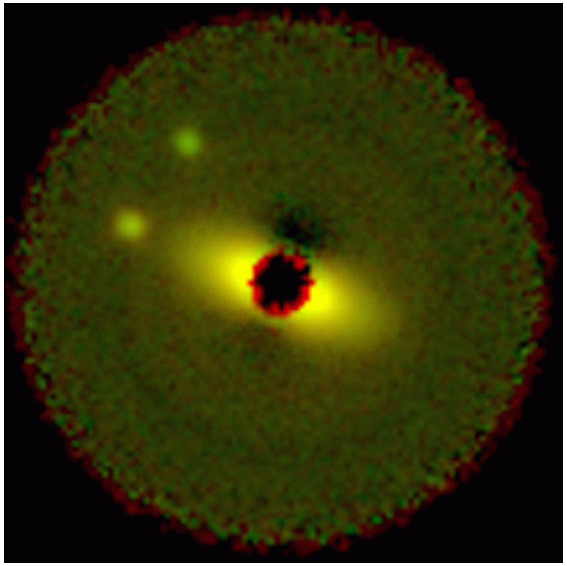


Image the internal structures of debris disks. There are 40 Spitzer-detected debris disks (Kuiper Belts) ≥ 100 zodi at d< 25 pc. Sensitivity will reach down to a few 10s of zodi equivalent in the 30-40 AU region.

Search for exozodiacal dust in TPF target stars, reaching down below 1 zodi @ 3 AU. Use dust transport theory to infer 1 AU dust population from 3 AU values.

Conclusions - Scattered Light

SEDs alone are not enough! Imaging is required to unambiguously determine disk properties.

Observed disks (primordial & debris) show wide range of overall structures, asymmetries, colors & dust properties

Small/medium missions may be able to get near 1 “zodi” but not at habitable zone “true zodi” separations.

Need improved theory to extrapolate to inner disk properties

Debris Disks - Keck Interferometer

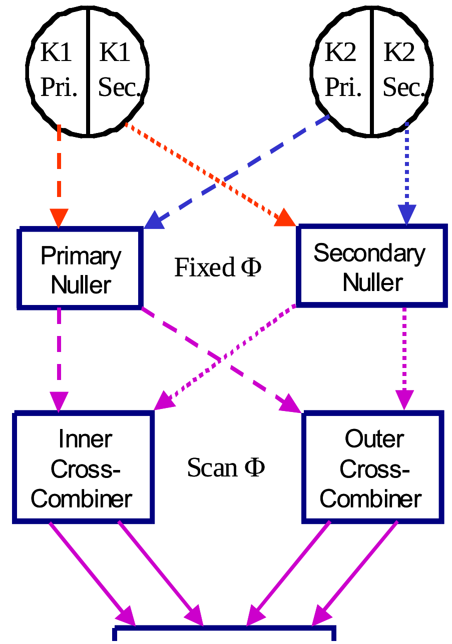
Rachel Akeson/ Rafael Millan-Gabet
Michelson Science Center

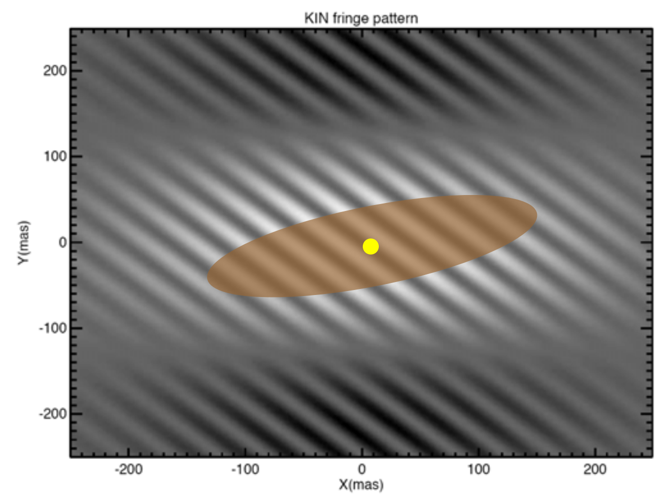
Keck Interferometer

- The Keck Interferometer is a NASA-funded project to connect the 10-m Keck telescopes as a Michelson interferometer and is jointly developed and operated by the Jet Propulsion Lab, the Michelson Science Center and the W.M. Keck Observatory
- The nuller instrument at KI operates in the N-band (8 to 14 microns) and was specifically designed to detect faint, mid-infrared emission surrounding nearby stars by suppressing the central starlight

Nuller architecture

- The KI nuller is a four-beam system
- The two Keck telescope apertures are split into left (primary) and right (secondary) halves at a dual-star module (DSM) at each telescope
- Two modified Mach-Zehnder nullers combine the light from the left halves and right halves on the long 85 m baseline
- The outputs of the two long baseline nullers are combined in a Michelson combiner – the cross combiner – with a short 4 m effective baseline.
- Modulation on the long baselines chops the central star to detect extended emission
- Modulation on short baseline allows fringe detection on top of the strong thermal background
- Fringe spacing is 25 mas, beam size is approximately 0.45" × 0.50", which rotates with the telescope pupil
- For a source at 10 pc, KI is sensitive to emission from 0.25 to 1.3 AU



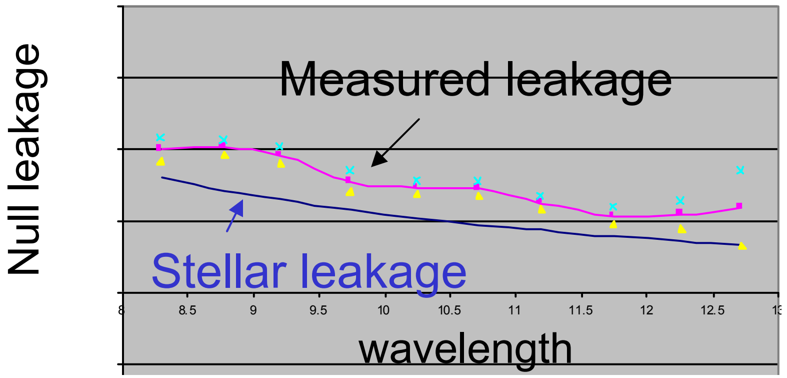


Current performance

- Current performance was measured in a series of validation tests on stars with a range of brightness which have no circumstellar material (to the best of our knowledge)
- From analysis of 21 observation sets (each comprising multiple target and calibrator scans over ~3 hrs)
  - KI achieves an external error of 0.25% rms in the null leakage in a broadband 8 – 9 um channel
  - 3 sigma detection level of ~150 zodi (where 1 zodi produces a flux ratio of $5x10^{-5}$ at 10 microns) after accounting for transmission through the long-baseline fringe pattern
  - Systematic errors observed early in the validation process have been minimized by altering the adaptive optics rotator angle, more closely matching the target and calibrator fluxes, and including only the shorter wavelengths in the broadband average
- Demonstrated sensitivity to 1.6 Jy
  - For sources near the flux limit, the null leakage is computed only in the broadband channel
    - Potential to go slightly fainter with longer integration times
  - For brighter sources, can use the 16 spectral channels

NASA Exo-zodical Dust Survey Key Science Program

- NASA is using the majority of its Keck time in 2008 to conduct a survey for exo-zodical dust around nearby stars
  - 32 nights from Feb 2008 to Jan 2009
- Teams were competitively selected to observe targets for future planet finding missions as well as known debris systems
  - Selected PI's: Hinz (U Arizona), Kuchner (GSFC), Serabyn (JPL)
  - 40 targets allocated, full list at http://msc.caltech.edu/software/KISupport/KeyScienceTargets.html
- Progress to date (3 of 8 runs): 15 sources observed
  - Excess emission detected for some sources
- Data become public 18 months after observation



KI nuller future prospects

- Major KI nulling development concluded in 2007
- Key Science program continues through January 2009
- Little or no support for nulling observations after January 2009
  - Will assess after completion of more Key Science obs
- KI observations in other modes will continue for at least a few years
  - New L-band capability (currently shared-risk) is relevant for bright debris disks and young star disks